AUTOMATED WATER MONITOR SYSTEM FIELD DEMONSTRATION TEST REPORT

VOLUME I EXECUTIVE SUMMARY

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VOLUME I
EXECUTIVE SUMMARY

SEPTEMBER 30, 1981

Prepared For:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER
MOFFETT FIELD, CA 94035

CONTRACT NAS2-9885

BY:

THE BOEING COMPANY
HOUSTON, TEXAS

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VOLUME 1

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ABSTRACT

As an outgrowth of its involvement in water reclamation and water quality monitoring for both spacecraft and domestic applications, the National Aeronautics and Space Administration conducted a project to develop and test an automated water quality monitoring system. The objective of this project was to develop and demonstrate a system that could perform water quality monitoring on-line and in real-time, much as it would be done in a spacecraft. The design goal was to develop a system with the capability to determine conformance to future high effluent quality standards and to increase the potential for reclamation and reuse of water. The resulting system includes conventional commercial sensors, NASA/contractor-developed sensors, an automated sample collection system, and a computerized data acquisition and reporting system. This report describes the system and documents the development of the NASA Water Monitor System (WMS) demonstration unit.

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TABLES

ACRONYMS

A/D	Analog to Digital Converter
ADAM	Air Data Acquisition and Monitoring
AER	Aeration
ATP	Adenosine Triphosphate
b	Constant
BOD	Biochemical Oxygen Demand
BV	Biosensor Valve
C	Concentration
$CaCO_3$	Calcium Carbonate
C_2CL_4	Tetrachloroethylene
CHLOR	Chlorination
CLAR	Clarification
CH_2Cl_2	Methylene Chloride
$C_2H_2Cl_2$	1,2 - Dichloroethylene
$CHCl_3$	Chloroform
CH_3CCl_3	1,1,1, - Trichloroethane
$CHBrCl_2$	Bromodichloromethane
C_2HCl_3	Trichloroethylene
$CHBr_2Cl$	Dibromochloromethane
$CHBr_3$	Bromoform
CLSS	Closed-Loop Stripping System
CO	Carbon Monoxide

COD	Chemical Oxygen Demand
^{o}C	Degrees Celsius
CRT	Cathode Ray Tube
CV	Coliform Valve
DAS	Data Acquisition System
DI	Deionized Water
DO	Dissolved Oxygen
DOY	Day of Year
DSLTB	Double Strength Lauryl Tryptose Broth
ECD	Electron Capture Detector
EDTA	Ethylene Diamine Tetra Acetic Acid
EVE	Environmental Verification and Evaluation
^{o}F	Degrees Fahrenheit
FID	Flame Ionization Detector
FILT	Filtration
floc	Flocculant
F/M	Food to Biomass Ratio
FTU	Formazin Turbidity Units
GAC	Granular Activated Carbon
GC	Gas Chromatograph
GLI	Great Lakes Instruments
gm, gms	Grams
gph	Gallons Per Hour

gpm	Gallons Per Minute
HCl	Hydrochloric Acid
HNO_3	Nitric Acid
H_2O, HOH	Water
H_2O_2	Hydrogen Peroxide
H_2	Hydrogen Gas
H^+	Hydrogen Ion
I	Input, Influent
IR	Infrared
JTU	Jackson Turbidity Unit
K	Constant
KH_2PO_4	Potassium Phosphate
LB/DAY	Pounds Per Day
LED	Light Emitting Diode
LIT, L, l	Liter
LTB	Lauryl Tryptose Broth
M	Molar Concentration
m	Constant, Meter
MCL	Maximum Concentration Limit
m^3/s	Cubic Meters Per Second (22.8 mgd)
mc/ml	Millions of Cells per Milliliter
mgal	Millions of Gallons
mgd	Millions of Gallons Per Day

ACRONYMS (Continued)

mg/l	Mil: grams Per Liter
ml	Millliliters
ml/min	Millliliters Per Minute
MPN	Most Probable Number
mv	Millivolt
N	Normal Concentration
n	Number of Samples
N_2	Nitrogen
NaOH	Sodium Hydroxide
NASA	National Aeronautics and Space Administration
NEDA	N-1 Napthyl-Ethylenediamine Hydrochloride
NH_3	Ammonia
NTU	Nephelometric Turbidity Units
O	Output
O/I	Effluent (Output)/Influent (Input)
O&M	Operations and Maintenance
OZON	Ozonation
PMT	Photomultiplier Tube
POX	Purgeable Organic Halogens
ppb	Parts Per Billion
ppm	Parts Per Million
psi	Pounds Per Square Inch
psig	Pounds per Square Inch Gage

ACRONYMS (Continued)

PVC	Polyvinyl Chloride
Q	Plant Flow, mgd
Q_W	Wasted Sludge, mgd
Q_R	Returned Sludge, mgd
r	Correlation Coefficient
RDOS	Real-Time Disk Operating System
RO	Reverse Osmosis
RPM	Revolutions Per Minute
RTD	Resistance Thermal Detector
S_a	Aerator Substrate, mg/l TOC
SCVWD-WRF/PA	Santa Clara Valley Water District-Water Reclamation Facility at Palo Alto
sec	Seconds
S_i	Primary Effluent Substrate, mg/l TOC
SiO_2	Silicon Dioxide
sorption	Adsorption or Absorption
TC	Total Carbon
TEC	Techtronics
THC	Total Halocarbons
TOC	Total Organic Carbon
TOX	Total Organic Halogens
T_s	Total Biomass in Aerator/Clarifier, mg
UV	Ultraviolet
V_a	Aerator Volume, mgal

ACRONYMS (Continued)

VAC	Volts Alternating Current
V_c	Clarifier Volume, mgal
VDC	Volts Direct Current
V_e	Chlorine Contact Volume, mgal
WMS	Water Monitor System
x	Independent Variable
X_a	Biomass In Aerator, mc/ml
X_c	Biomass in Clarifier Effluent, mc/ml
X_e	Biomass in Effluent From Chlorine Contact Tank, mc/ml
Y	Mass Yield of Biomass per Unit Substrate Consumed, mg/mg
y	Dependent Variable
μ	Microns, Micro
#	Number
%	Percent
σ	Standard Deviation
σ_E	Standard Error of Estimate
Z	The Number of Standard Deviations from the Mean

SECTION 1.0

INTRODUCTION

BACKGROUND

Since the beginning of manned space flight, NASA has been involved in the analysis, design, development, testing, and application of systems for water supply, water monitoring, and waste management. Throughout the earlier programs (Mercury through Apollo-Soyuz), it was possible to discard water after it had been used. However, long-duration multipersonnel missions or space stations will not be able to accept this penalty because a 6-man crew could easily use 113 to 136 kilograms (250 to 300 pounds) of water per day, or 36 to 45 megagrams (40 to 50 tons) per year (Reference 1). Thus, reuse of water will be essential. In preparation for this future requirement, NASA has worked extensively in the development and demonstration of processes for the recovery of water from all potential sources (e.g., humidity condensate, used washwater, urine, and fecal flush water), the monitoring of spacecraft water for both chemical and biological contamination, and the reduction of waste to small-volume chemically and biologically inactive residues. The experience and facilities NASA has acquired in the performance of this work are directly applicable to the development of compact and efficient water reclamation and monitoring systems for domestic use. Thus, as part of its continuing effort to transfer advanced technology to the community and in recognition of the increasing freshwater shortage and the national concern about pollution, NASA has undertaken several programs in pollution monitoring and water reuse technology.

In 1971, NASA began a program to design a Modular Integrated Utility System (MIUS), Reference 2. The purpose of the MIUS program was to develop techniques for integrating electrical power generation, water processing, solid and liquid waste management, and environmental conditioning, using residual energy for utility functions. This program was conducted in cooperation with other government agencies such as the Department of Housing and Urban Development, the National Bureau of Standards, and the Environmental Protection Agency.

The NASA work on MIUS included reviewing water reuse applications such as cooling towers, home recirculation systems involving non-potable applications, and garden irrigation (Reference 3). However, it was discovered that no national standards existed to determine the acceptability of treated wastewater for reuse, particularly for human consumption. In addition, no monitoring system was available to provide adequate and timely verification of total water quality. These key issues, common to both NASA spacecraft and Earth-bound application, led to the development of an automated water quality monitoring system to ensure the safety of treated wastewater.

A survey of in-house NASA developments relative to water monitoring revealed the following items with potential for near-term applications.

1. A water quality monitoring system at the NASA Lyndon B. Johnson Space Center (JSC) developed for spacecraft application that incorporated conventional sensors and a chemiluminescence biosensor (Reference 4).

2. A coliform detection concept using detection of metabolic gas evolution being developed on a laboratory basis at the NASA Langley Research Center (References 5 and 6).

3. Bioluminescence techniques sensitive to adenosine triphosphate (ATP) in living organisms being studied at the NASA Goddard Space Flight Center.

None of these developments were in an on-line configuration, nor did they provide any type of data acquisition and display system. The Water Monitor System (WMS) project begun at JSC was designed to integrate these developments into an on-line system that could provide a complete water quality overview.

A phased development program to build the WMS was implemented. The phases were as follows:

Phase I: Assembly and testing of a breadboard system in the MIUS Integrated Systems Test (MIST) laboratory at JSC.

Phase II: Assembly and testing of a field demonstration system in the MIST laboratory.

Phase III: System demonstration in a community wastewater treatment facility.

Phase I was concluded in February 1975 and the results are described in Reference 7. Phase II was completed in February 1977. Phase III was concluded in February 1981.

PROGRAM OBJECTIVES

Previous water quality testing in the MIST facility, as in most community treatment plants, was done primarily on a laboratory basis and often required 1 to 2 weeks to get laboratory results. Even under the best conditions, the determination of some parameters, such as biological oxygen demand (BOD) and Escherichia coli (fecal coliform), required 4 to 5 days. The objective of the WMS was to perform water quality monitoring on-line and in real-time; much as it would be done in a spacecraft. The design goal was to develop a system with the capability to determine conformance to future high effluent quality standards and to increase the potential for reclamation and reuse of water.

The following program objectives were established:

1. To develop an automated WMS for wastewater treatment system effluent monitoring.

2. To focus and accelerate development of real-time micro-organism sensor technology transfer efforts within NASA.

3. To demonstrate feasibility and reliability by correlating data with standard laboratory techniques.

4. To develop the system to a field demonstration configuration and demonstrate it to municipalities.

The objectives of the field demonstration were further expanded after it was underway at the Santa Clara Valley Water District's Water Reclamation Facility at Palo Alto, California.

1. To determine the steady-state performance (ability to remove contaminants) of the water reclamation facility unit process based on WMS data.

2. To determine unit process and reclamation facility availability.

3. To determine reclamation facility reliability.

4. To determine reclamation facility operating and maintenance costs.

5. To determine similar parameters for the WMS; i.e., performance, availability, reliability, and operating and maintenance costs.

SCOPE

The NASA approach to the development of the WMS was to place emphasis on the NASA biological sensors and the total WMS concept. Performance of the biological sensors was of special interest because they were in the developmental stage. Although NASA appreciated the fact that selection of commercial sensors was an important task, system development time and program dollars were not of a scope to permit extensive testing of the wide range of candidate equipment for each parameter. Therefore, some sensors installed in the WMS performed better than others. The sensors chosen represented a good cross section of the sensors commercially available. Additionally, installation in the WMS was not to be construed as an endorsement by NASA; it was the overall system approach to on-line monitoring that was considered to be of importance.

The Phase II effort, consisting of the development, assembly, and initial checkout of the field demonstration unit was initiated in March 1975 and completed in February 1977. Phase III field testing of the demonstration unit was divided into two parts. The first part occurred during April and May 1977 at the Southwest Wastewater Treatment Plant (SWTP) in Houston, Texas. The second part of Phase III occurred from June 1977 to February 1981 at the Santa Clara Valley Water District's Water Reclamation Facility in Palo Alto, California. A block diagram of these activities is shown in Figure 1. The tasks were performed under contracts NAS9-15060 and NAS2-9885 with The Boeing Company, Houston, Texas. The early tasks of the program up to and including the first part of Phase III were accomplished under the administration of NASA's Johnson Space Center. The second part of Phase III was accomplished under the direction of NASA's Ames Research Center.

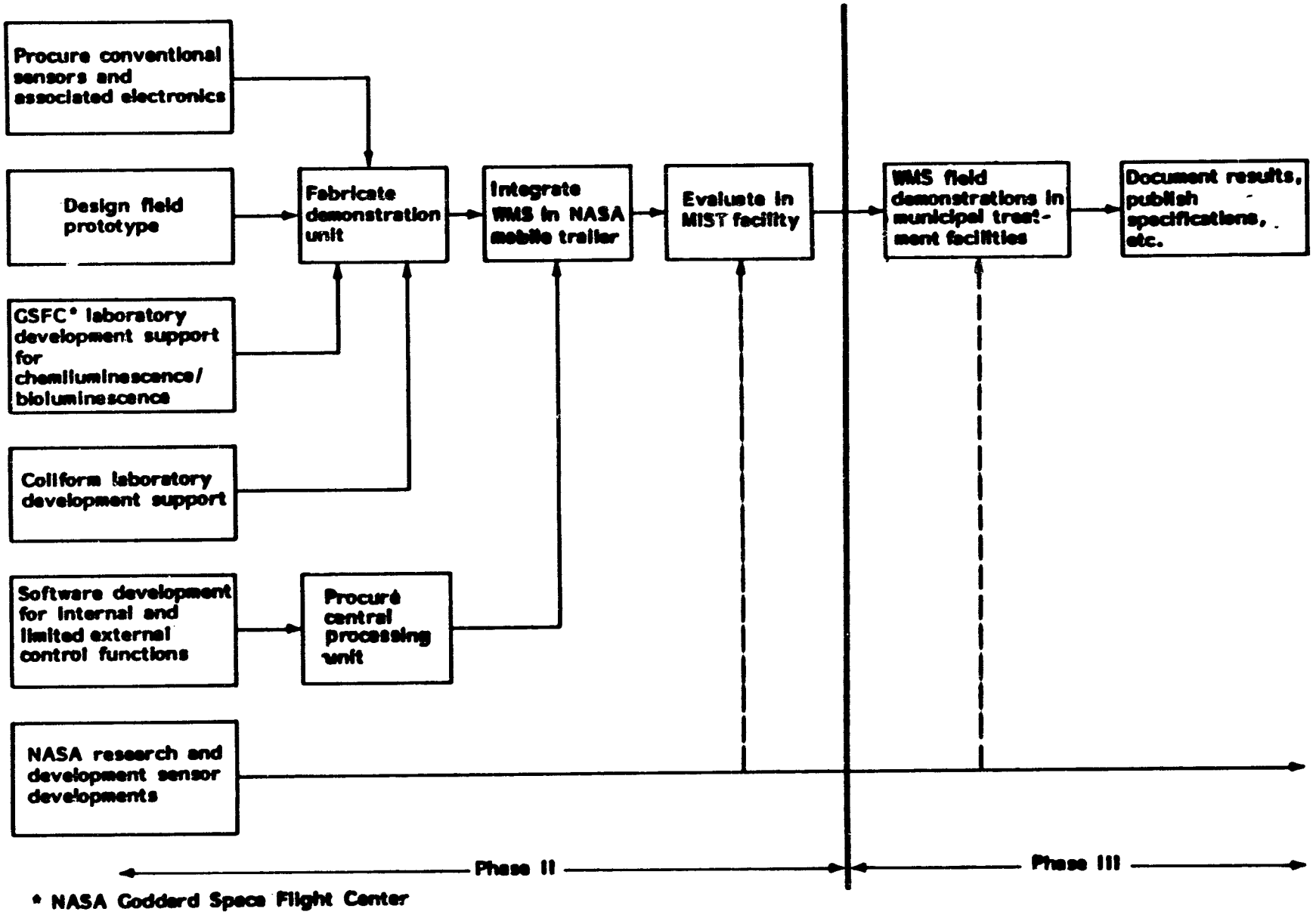

Figure 1 Block Diagram of the WMS Project; Phases II and III

SECTION 2.0

WMS (WATER MONITOR SYSTEM)

DESCRIPTION

This section describes the WMS and each of the subsystems. The performance characteristics of each subsystem are evaluated. Operations and maintenance costs are presented for each subsystem. Also included is a discussion of the statistical analysis procedures used in the evaluation of the data obtained by the WMS.

General

The WMS is contained in a 2.4 x 9.0m (8 x 30 ft) transportable semitrailer that includes all the support equipment required to sample various process stages of waste treatment facilities. The WMS configuration is depicted in Figure 2. The instrumentation and computer systems are housed within the trailer, and the sample pumping system, filters, and compressed air supply are secured beneath the trailer. The sample collection and distribution system provides the capability to sample any one of six different sources of water within the treatment process. The WMS has the capability to handle up to 40 data channels. In addition to the GC, the WMS measures 14 water quality parameters. The sensors measuring these parameters are shown in Table 1 with the range, calibration frequency, and the required chemical replacement frequency. With the exception of the last three sensors shown in the table, the sensors are commercially available models that were either available from NASA or bought off the shelf. Where appropriate, these commercial sensors were modified to allow for automatic computer calibration and data acquisition. The remaining three sensors (the coliform detector, the gas chromatograph, and the chemiluminescence biosensor) are based on NASA-developed technology and are unique to the WMS. The elements which comprise the WMS are outlined below. A more complete description of the sensors is presented in reference 8.

Utilities

All utility functions necessary to operate the WMS equipment (except tap water and electrical power) are provided by the WMS trailer. These include air conditioning, compressed air, deionized water, and various reagent gases.

Sample Collection and Distribution System

The sample collection system was designed for multipoint sampling whereby sampling can be accomplished in and about various locations of a wastewater treatment facility. The system has the capability of providing water samples

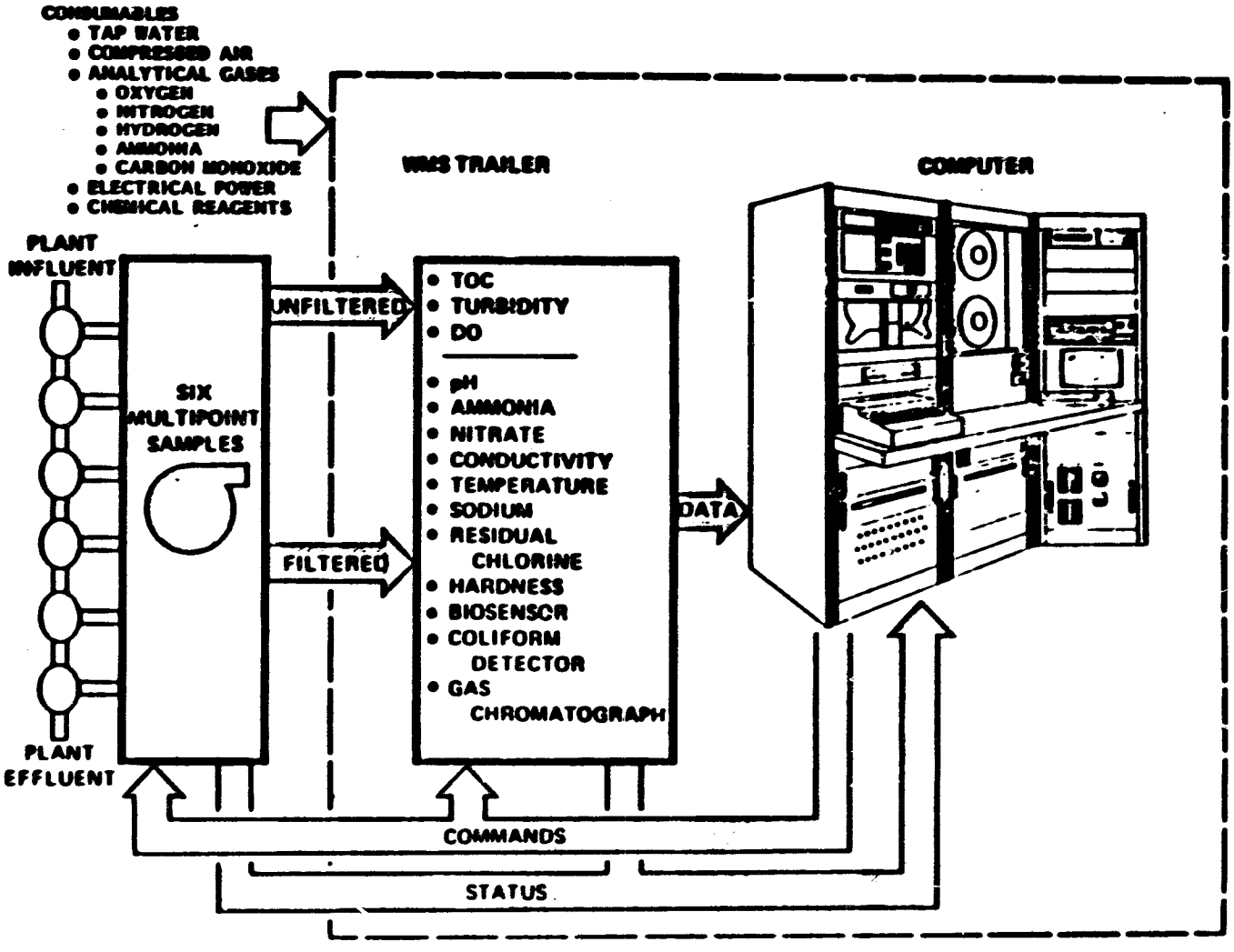

Figure 2 Water Monitor System Configuration

TABLE 1
WMS SENSORS

SENSOR	RANGE	STANDARDIZATION FREQUENCY	CHEMICAL REPLACEMENT FREQUENCY
TOC (IR ANALYZER)	0.1 - 1,000 mg/l	DAILY	STD - WEEKLY
HARDNESS (ELECTRODES)	1 - 10,000 mg/l $CaCO_3$	DAILY	STD - WEEKLY REAGENT - 3 MONTHS
RESIDUAL CHLORINE (ELECTRODES)	0.1 - 1,000 mg/l	DAILY	STD - WEEKLY REAGENTS (2) - 3 MONTHS
NITRATE/NITRITE (COLORIMETRIC)	0 - 80 mg/l - N	DAILY	STD - WEEKLY REAGENTS (2) - WEEKLY
AMMONIA (COLORIMETRIC)	0 - 80 mg/l - N	DAILY	STD - WEEKLY REAGENTS (2) - WEEKLY
SODIUM (ELECTRODE)	10 - 1,000 mg/l	DAILY	STD - EVERY 3 DAYS
pH (ELECTRODE)	2 - 12 pH units	WEEKLY	STD - WEEKLY
CONDUCTIVITY (CELL)	0 - 2,000 μmho/cm	WEEKLY	NONE REQUIRED
TEMPERATURE (RTD)	0 - 200°F	WEEKLY	NONE REQUIRED
TURBIDITY (PHOTOMETER)	0.1 - 5,000 mg/l SiO_2	WEEKLY	NONE REQUIRED
DISSOLVED OXYGEN (ELECTRODE)	0 - 20 mg/l	WEEKLY	NONE REQUIRED
COLIFORM DETECTOR	≥ 1 particle /17 ml		EVERY OTHER DAY
GAS CHROMATOGRAPH	≥ 1 μg/l	EVERY TWO WEEKS	MONTHLY (GASES)
CHEMILUMI-NESCENCE BIOSENSOR (TOTAL & VIABLE)	≥ 10^5 particles/ml	EVERY TWO WEEKS	EVERY 3 DAYS

from six different locations at predetermined intervals. Figure 3 presents the configuration and flow schematic of the system.

Total and Viable Biomass

A chemiluminescence biosensor has been developed for monitoring bacterial population in wastewater streams. The system employs the alkaline luminol-hydrogen peroxide reaction with iron porphyrins as a total bacteria monitor. Hydrogen peroxide pretreatment, reaction rate differentiation, and EDTA allow the resolution and quantitation of bacteria in the presence of the interfering materials associated with wastewater effluents. Incorporation of a carbon monoxide technique permits the measurement of both total and viable bacteria in an automated flowing system.

To measure viable bacteria with an automated luminol chemiluminescence system, the laboratory single sample injection method developed at Goddard Space Flight Center was converted to a flowing system where reagents and samples are transported with peristaltic pumps. The major problem was the handling of the carbon monoxide-treated sample. It was known that light reverses the binding of the carbon monoxide with iron porphyrins of viable bacteria. The carbon monoxide pretreatment had to be performed in the dark and the sample had to be protected from light until after the subsequent analysis. This was achieved by locating the carbon monoxide bubble chamber in a dark box and by using black tubing for transferring the sample from the chamber to the reaction coil.

In addition to the carbon monoxide required for the determination of viable bacteria, air had to be bubbled through the sample for accurate determination of total bacteria. Without the air treatment, total bacteria counts were artifically high, a fact still unexplained.

The biosensor schedule originally required 2 hours for a measurement of both total and viable bacteria. The schedule was later shortened to 1 hour after tests confirmed that sample flush, air/carbon monoxide treatments, and analysis could be accomplished with sufficient quantitative accuracy.

A standard calibration method was developed to insure the accuracy and repeatability of the sensor. Calibrations were established using the Coulter electronic particle counter and the firefly luciferase - ATP assay for total and viable bacteria, respectively. These are illustrated in Figure 4 and Figure 5. They were reproducible for samples of cultured coliform bacteria or effluent samples. The correlation coefficient was 0.96. The viable bacteria correlation curve illustrated in Figure 5 shows much more scatter when cultured bacteria and effluent samples are compared. This may be due not so much to variations in biosensor response but to variations in the ATP levels within the organisms grown in different environments and subject to various degrees of stress.

The standard curve generated from the measurement of total bacteria is used for the calibration of the sensor. The stability and repeatability of these measurements make it the method of choice. Extensive research in the

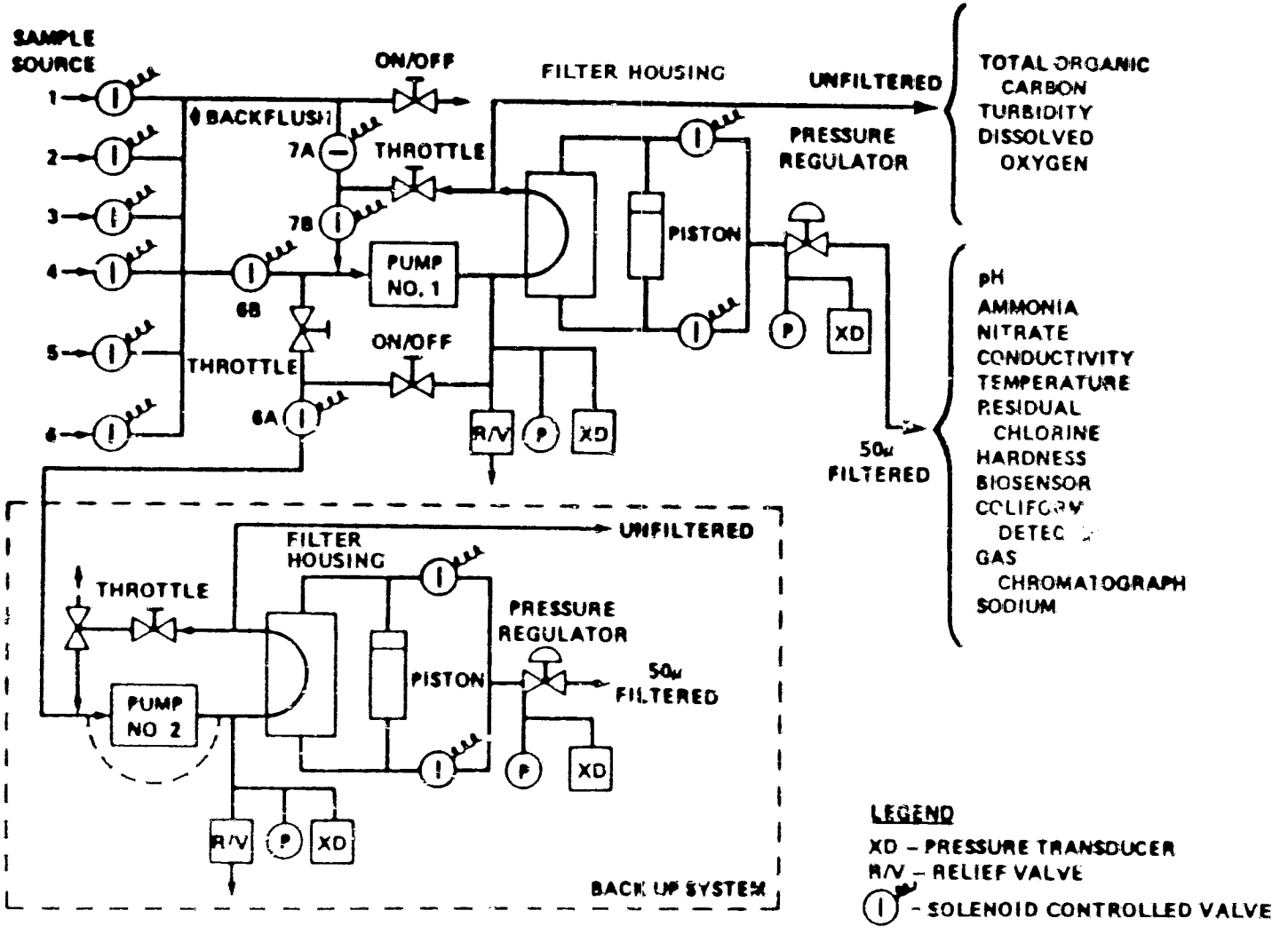

Figure 3 Sample Collection and Distribution Flow Schematic

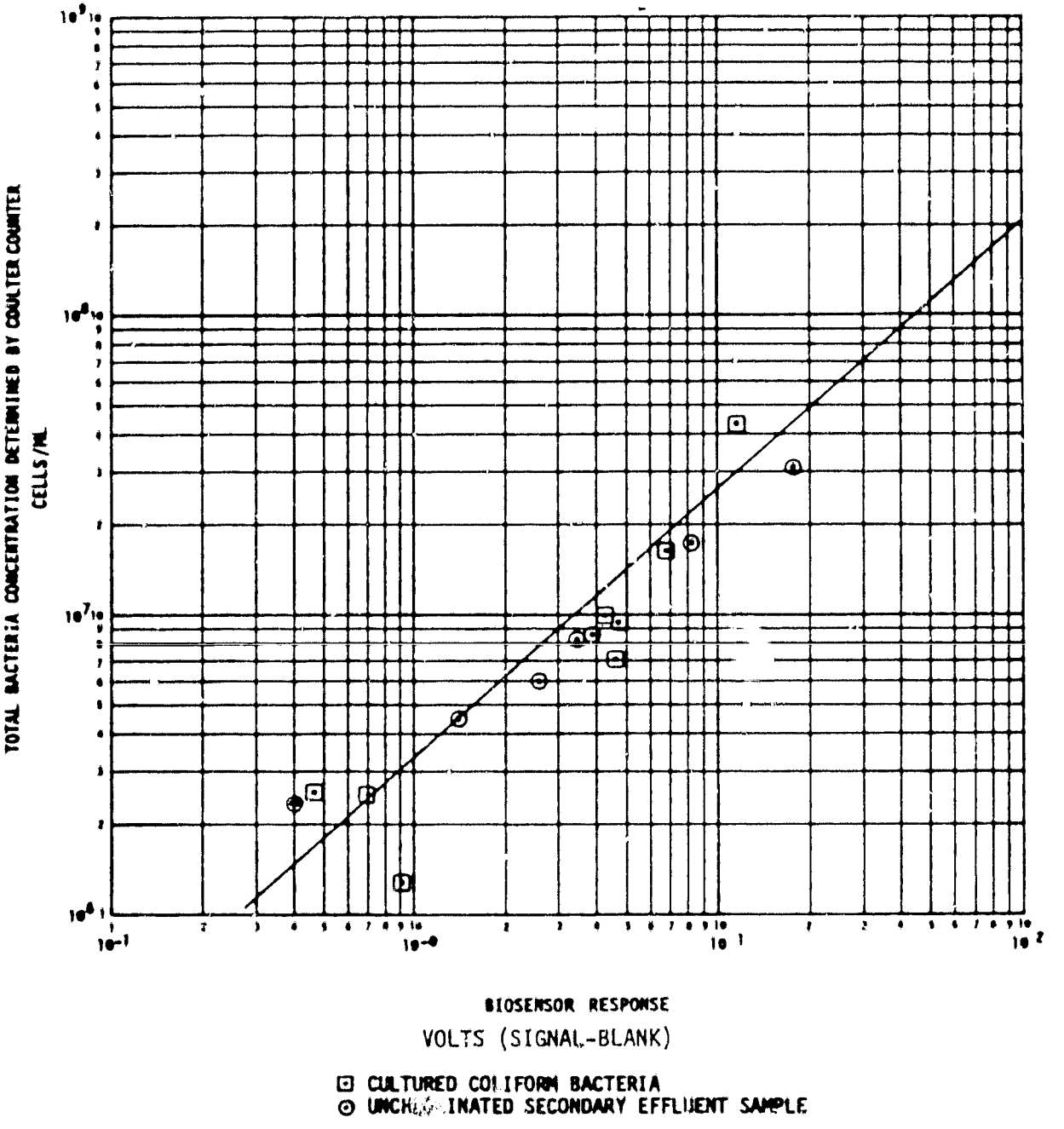

Figure 4 Biosensor Calibration Curve Established for Total Bacteria

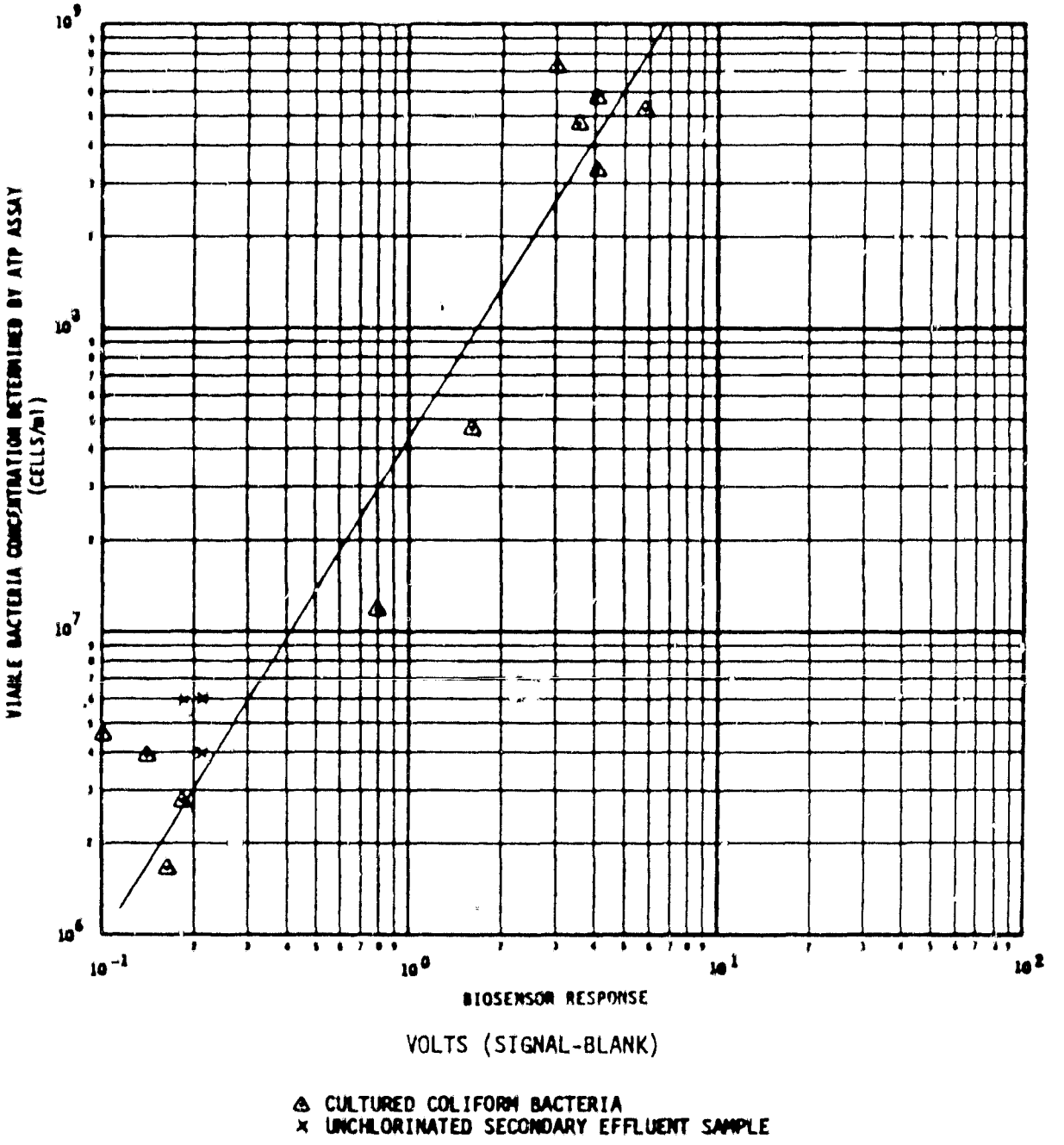

Figure 5 **Biosensor Response versus Viable Bacteria as Determined by the Firefly Luciferase** - ATP Assay

laboratory supports the extension of the method to calculate viable bacteria with relative confidence.

Figure 6 is a schematic of the chemiluminescence biosensor including positions of Buchler peristaltic pumps, valves, and other associated apparatus. A sample is pumped at 4.35 ml/min. and mixed with 0.02% H_2O_2 flowing at 0.35 ml/min. The sample is in contact with the final 0.0015% solution of H_2O_2 for 2 minutes. This H_2O_2 pretreatment step is designed to eliminate interferences from extracellular iron porphyrins by oxidative degradation while not significantly affecting intracellular porphyrins protected by the cellular membrane. Ninety-five percent removal of these interferences is effected using this pretreatment.

The H_2O_2 pretreated sample is pumped into the bubble chamber at 4.7 ml/min. An assay of the air-treated sample produces a measurement of total bacteria, live as well as dead organisms, due to the stability of the iron porphyrins within an intact cellular membrane. An analysis of a carbon monoxide-bubbled sample is a measure of dead bacteria only.

An actively respiring bacterium absorbs carbon monoxide that irreversibly binds with the iron porphyrin members of the electron transport chain. Luminol chemiluminescently reacts with the oxidized iron porphyrins of the dead bacteria; however, no reaction occurs with the reduced carbon monoxide-complexed iron porphyrins found in the metabolizing organisms. The difference in chemiluminescent response between an air-treated sample (live and dead bacteria) and carbon monoxide-treated bacteria (dead bacteria only) can be directly related to the concentration of metabolizing bacteria.

The air/CO-treated sample, pumped at 0.20 ml/min., is then mixed with the luminol reagent (5.64×10^{-3} M luminol, 1.5 N sodium hydroxide, 40.6×10^{-3} M EDTA, and 0.1% H_2O_2) at 0.20 ml/min. A 10-second residence time is incorporated in the line before the photomultiplier tube to eliminate the short-lived chemiluminescence signals from interfering agents such as chlorine and transition metals.

The chemiluminescent signal is measured using an Aminco Chem-Glow Photometer equipped with a coiled glass flow cell. The computer records the output of the photometer and converts the values to bacteria counts in units of millions of cells/ml based on blank and calibration factors.

Table 2 contains the schedule for computer actuation of valves and commands to calculate the results. The first 5 minutes of the schedule, step 1, allows the sample lines to flush without flowing sample to the bubble chamber. This step is designed to prevent cross-contamination of the previous hour's sample with the current sample source. Step 2 fills the bubble chamber with sample while bubbling air through the sample for a total of 10 minutes. The chemiluminescence response is measured and recorded during step 3 which lasts 19 minutes. Step 4 signals the computer to average the last five recorded values and calculate the total bacteria concentrations based on the calibration factors. Steps 5, 6, and 7 are similar to steps 2, 3, and 4, except carbon

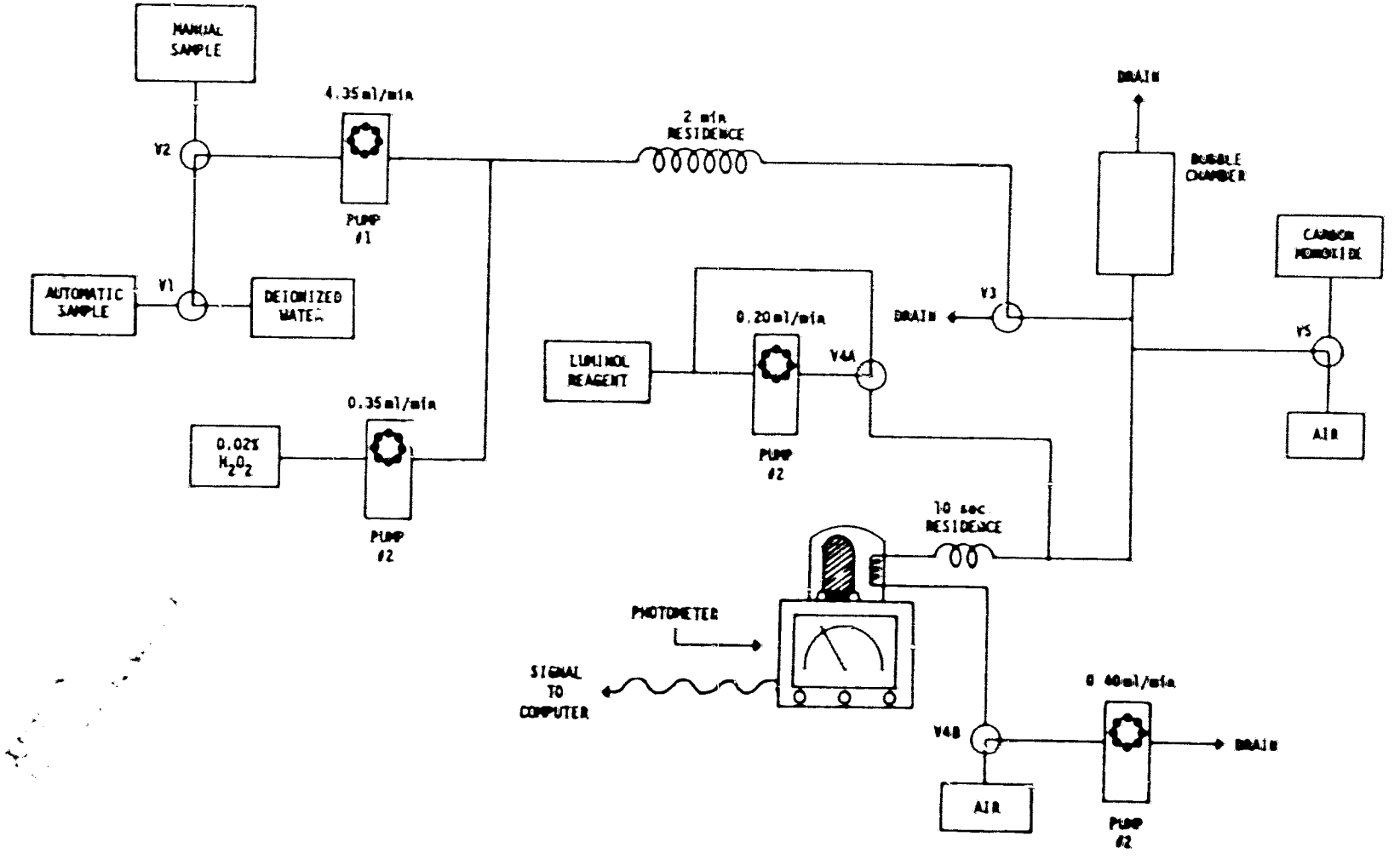

Figure 6 Chemiluminescence Biosensor Schematic for Monitoring Total and Viable Bacteria

monoxide is bubbled for use in the calculation of viable bacteria. The computer retains the value for total bacteria calculated in step 4, then subtracts the value of dead organisms calculated in step 7. The difference is recorded as the viable bacteria.

TABLE 2. BIOSENSOR HOURLY SCHEDULE

STEP	VALVE ENERGIZED TIME HR:MIN:SEC	CUMULATIVE TIME HR:MIN:SEC	ENERGIZED VALVES
1.	0: 5: 0	0: 5: 0	1, 3
2.	0:10: 0	0:15: 0	1
3.	0:19: 0	0:34: 0	1, 3, 4
4.	0: 1: 0	0:35: 0	1, 3, 4
5.	0: 5: 0	0:40: 0	1, 3, 5
6.	0:19: 0	0:59: 0	1, 3, 4, 5
7.	0: 1: 0	1: 0: 0	1, 3, 4, 5

Total Residual Chlorine

An Orion Model 1125 Chlorine Analyzer measures the residual chlorine in continuous samples by the potentiometric method. It operates on the principle that chlorine will liberate free iodine from potassium iodide solutions when the pH is 8 or lower. The sample is mixed with a reagent and pumped through a reaction heater and constant temperature analysis chamber. In the chamber, the mixture passes between a sodium electrode and redox electrode. The electrodes are connected to the analyzer's electronics system which gives a direct chlorine concentration reading on a four-cycle logarithmic scale calibrated to read from 0.1 to 1000 mg/l.

Turbidity

A Sigrist Photometer Turbidimeter Model UP 52-TJ determines the turbidity of a continuous sample stream by comparison with a nephelometric standard. The Model UP 52-TJ has four measuring attachments of different ranges. Two of the units use falling-stream flow cells with ranges of 2-1000 and 2000-15,000 mg/l (SiO_2); one uses a surface scatter-flow cell with a range of 5-100 mg/l; and one uses a splash-flow cell with a range of 0.5-20 mg/l. All of them use a dual beam optical measuring bridge. The flow attachment used during the current test period was the Model TJ25 which measures light scatter at 25 degrees in a falling stream. The manufacturer claims that this configuration gives the best sensitivity for detecting low concentrations of biological solids.

Dissolved Oxygen

A Delta Scientific Series 6310 Automatic Analyzer continuously measures dissolved oxygen in a sample stream. The patented DO probe consists of gold and silver electrodes mounted in a PVC body. A Teflon membrane forms an oxygen-permeable barrier between the water being tested and the electrolyte in the probe. A voltage is applied across the electrode and as oxygen passes through the membrane, it produces an electrical current proportional to its concentration. DO readings in mg/l in the ranges of 0-2, 0-10, or 0-20 are displayed.

TOC (Total Organic Carbon)/TOD (Total Oxygen Demand)

The TOC measurements presented in this report were obtained using one of two TOC analyzers. The TOC analyzer originally installed in the WMS was an Astro Ecology Model 1100 TOC/TC Analyzer using a high temperature reactor to obtain conversion of organic carbon to carbon dioxide. The replacement low temperature TOC analyzer, Astro Ecology Model 1800, was installed in April 1980. A more complete description of the two analyzers follows.

The Astro Ecology Corporation high temperature TOC analyzer simultaneously determines either TC (total carbon) or TOC on aqueous samples containing solid particulates up to 2000 micrometers in diameter. Measurement ranges from 0-10 mg/l or 0-500 mg/l of carbon are available. Fifty ml/min. of sample are continuously pumped into a mixing chamber and gas scrubber assembly where it is mixed with phosphoric acid to reduce the pH to 2. Inorganic carbon is converted to carbon dioxide which is vented to an air stream. A portion of the scrubbed, carbonate-free sample (2 ml/min.) is pumped into a combustion chamber and combined with a metered air stream (79% oxygen). The air provides the oxygen for combustion. The sample remains in the chamber at 850°C long enough for full combustion to occur. The products of combustion and excess air leave the reactor and enter a water-cooled liquid/gas separation assembly which removes condensed vapors. The remaining gases are routed to an infrared analyzer where the amount of carbon dioxide is measured and converted to units of TOC.

The Astro Ecology Corporation low temperature TOC analyzer is capable of measuring either TC or TOC. The analyzer is continuously operated in the TOC mode for WMS applications. The following theory of operation refers to Figure 7. The incoming sample is pumped into the analyzer at the nominal rate of 28 ml/min. by P1(M1), a peristaltic pump. Approximately 4 ml/min. of this flow is transferred via P3(M2) to the inorganic carbon scrubber assembly (S-1), and the balance is bypassed to drain. A phosphoric acid solution, pumped by P5(M3) at .21 ml/min. from acid reservoir (R-2), is added to this stream before it reaches the CO_2 scrubber. This acid addition converts 99% of the inorganic carbon to CO_2 which is then scrubbed out of the solution. Scrubber oxygen flow is introduced at the bottom of (S-1) and is controlled by FIC-2 at 150 ml/min. All excess sample entering (S-1) is bypassed by overflow to drain. Pump P4(M2) draws 0.3 ml/min. from (S-1)'s overflow. This sample is mixed first with a carrier gas (zero grade oxygen) and then with a persulfate solution, delivered by P6(M3) at .21 ml/min., and delivered to the reactor module UV-1. In the reactor module all carbon in the sample is converted to CO_2. The oxidized

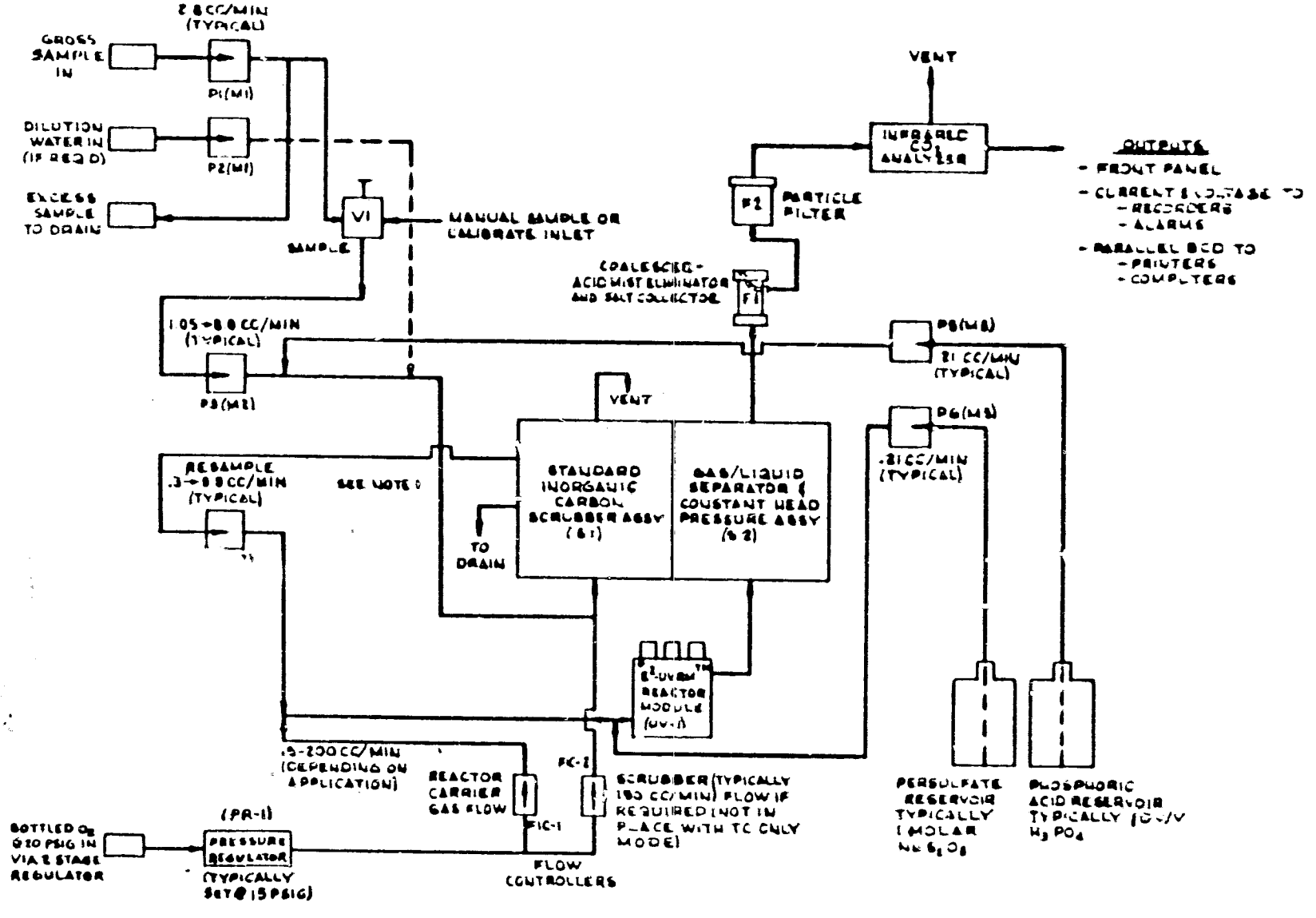

Figure 7 Total Organic Carbon Sensor Flow Schematic

sample solution then passes through (S-2) (gas-liquid separator and constant head overflow assembly) and the liquid portion is directed to drain. The vapor portion of the sample, now laden with CO_2 and other by-products, leaves from the top of (S-2). This vapor passes through (F-2) (filter element) before delivery to the infrared analyzer for CO_2 analysis.

The Astro Ecology Corporation TOD (Total Oxygen Demand) Analyzer was used for the first portion of the test period. Due to difficulties with the sensitivity of the analyzer, it was not used during the last half of the test period at the SCVWD Reclamation Facility.

The TOD analyzer determines oxygen demand for hydrogen, nitrogen, sulfur, and carbon compounds found in the sample water. It receives the non-condensable gases from the TOC analyzer following the carbon dioxide analysis and passes them through a solid electrolyte oxygen detector. The oxygen depletion, based on the amount of air fed to the reactor, is measured and translated into units of TOD.

Ammonia

A Delta Scientific Model 8119 Ammonia Analyzer continuously measures ammonia in sample water by spectrophotometric analysis. The intensity of the blue color developed by the reaction of ammonia with phenol and hypochlorite in an alkaline medium is proportional to the concentration of ammonia in the sample. The analyzer has a minimum sensitivity of 0-1 mg/l ammonia, and no upper limit with dilution.

Nitrate/Nitrite

A Delta Scientific Model 8138-153105-002XX1 Nitrate Analyzer continuously measures nitrate/nitrite concentrations in the sample stream by spectrophotometric analysis. Nitrates are reduced to nitrites in a cadmium-reducing column. The nitrites are then reacted with sulfanilamide and NEDA in an acid solution to form the azo dye. The color intensity developed is a measure of the nitrate plus nitrite concentration in the sample. The concentration of nitrites may be determined separately by bypassing of the cadmium column. Nitrate/nitrice concentrations above 0.4 mg/l are too dark for useful discrimination; therefore, dilution of the sample is required for most measurements.

pH

The GLI (Great Lakes Instruments) Model 70 Analyzer measures pH using the differential electrode technique to compare a pH electrode to a standard electrode containing a chemical pH standard. The probe is housed in a 1 1/2-inch PVC tee to increase the flow velocity across the probe.

Conductivity

The sensor used to measure the ionic content of the water sample is a Beckman Type R15 Solu Bridge Conductivity Indicator with a temperature-compensated epoxy flow-through cell, type CEL-VDJ4-KF. The cell constant is 4.0, permitting measurements in the range of 0-2000 mhos/cm.

Temperature

The Action Pac RTD's (Resistance Thermal Detectors) are used to measure sample temperatures. The RTD probe detects changes in potential between two electrodes as the temperature changes and converts this to a 0 to 5-volt signal. The probe is sensitive to 0.1°F and reads from 0-200°F.

Hardness

An Orion Model 1132 Hardness Analyzer continuously monitors the sample stream for hardness, a measure of calcium and magnesium ions in water. The technique used is proprietary to Orion Instrument Company. In general the method involves the chelation of all divalent ions by a complexing agent, followed by the addition of a "substitution" ion which selectively releases calcium ions. A "tag" ion is added at molar concentrations 100 times greater than the maximum possible ionic strength. A reference electrode is selective to this tag ion, and the sensing electrode is selective to the substitution ion. The electrodes are connected to the analyzer's electronics system which gives a direct hardness reading on a four-cycle logarithmic scale calibrated to read from 0.1 to 1000 mg/l.

Sodium

The Beckman Model 9415 Sodium Ion Analyzer determines the concentration of sodium in a sample stream by measuring the potential between a Beckman 633951 Sodium Ion Electrode and a Beckman 19604 reference electrode. The electrode potential is directly proportional to the logarithm of the active sodium concentration. The response of the sodium electrode can be affected by several other monovalent cations. Usually, hydrogen is the only interfering ion with sufficient concentration to be a problem. To eliminate this interference, all solutions are pH adjusted with ammonia to suppress the hydrogen ion concentration. Temperature control is provided by a heat exchanger located upstream of the electrode flow chamber.

Gas Chromatograph

The gas chromatograph quantitatively measures nine volatile halogenated hydrocarbons. The system, linked to the 50-μ filtered multipoint sample source, automatically injects 120 l of sample into a preparative gas chromatograph which separates the organic compounds from the water. The organics are collected on a Tenax GC trap which is heated to introduce the compounds into the analytical gas chromatograph for accurate quantitation at the microgram per liter level. The following compounds are routinely monitored during the 50-minute analysis:

1) Tetrachloroethylene
2) Methylene Chloride
3) 1,2-Dichloroethylene
4) Chloroform
5) 1,1,1-Trichloroethane
6) Bromodichloromethane
7) Trichloroethylene
8) Dibromochloromethane
9) Bromoform

The system is interfaced with the Nova 3 for data transfer, storage, and retrieval.

The automated gas chromatograph consists of two basic subsystems. The first subsystem, which includes a sampling valve, preparative gas chromatograph and trap, is required to separate and concentrate the volatile chlorinated organics from the water sample. The concentrated sample is then routed to the analytical gas chromatograph which performs the quantitative analysis. Figure 8 is a schematic of the complete system.

The preparative gas chromatograph is a Hewlett-Packard Model 5710 equipped with a thermal conductivity detector. This chromatograph is fitted with a short Sorbital precolumn and a pair of 0.635 cm o.d. x 137 cm stainless steel columns packed with 10% Sorbitol and 0.5% Igepal 50-880 on 50/80 mesh Gas Chrom Q. The column oven is operated isothermally at 105°C. A 99.999% nitrogen carrier gas flow is maintained at 15 ml/min. The sample is introduced into the preparative gas chromatograph via a Bendix liquid sampling valve mounted on top of the unit. The sampling valve injection port is maintained at 150°C.

The preparative gas chromatograph is fitted with an external valve oven maintained at 150°C. This valve oven houses two automatically controlled Carle Model 2014 microvolume sampling valves and lines connecting the preparative and analytical gas chromatograph subsystems. Valve 2 permits selection of the water column in the preparative gas chromatograph. Valve 1 allows sample flow to pass through the trap or to the atmosphere. A trap consisting of 10.2 cm x 15.2 cm stainless steel tubing packed with 60/80 mesh Tenax GC extends outside the external oven to allow rapid heating and cooling. Heating is accomplished by a commerical blower/heater, and cooling is attained by blowing ambient air across the trap.

The analytical gas chromatograph consists of a Hewlett-Packard Model 5840 equipped with an electron capture detector. The detector oven is maintained at 325°C and the injection port temperature at 175°C. The analytical column consists of a 355 cm x 0.312 cm o.d. stainless steel column packed with 0.2% Supelco SP-1000 on 80/100 Carbopak C. The carrier gas flow is maintained at 14 ml/min. For an analysis, the column is maintained at 80°C for 28 minutes, then programmed to rise to 175°C at 8°/minute. A mixture of 95% argon and 5% methane is used as the carrier gas in the analytical gas chromatograph.

The gas chromatograph system is interfaced to the computer system for calculations and storage of data. The area values calculated by the gas chromatograph are transferred to the computer through the communications interface. The computer calculates the absolute concentrations for the nine compounds based on established calibration curves. The concentrations of the compounds are then stored on the disk system for later retrieval.

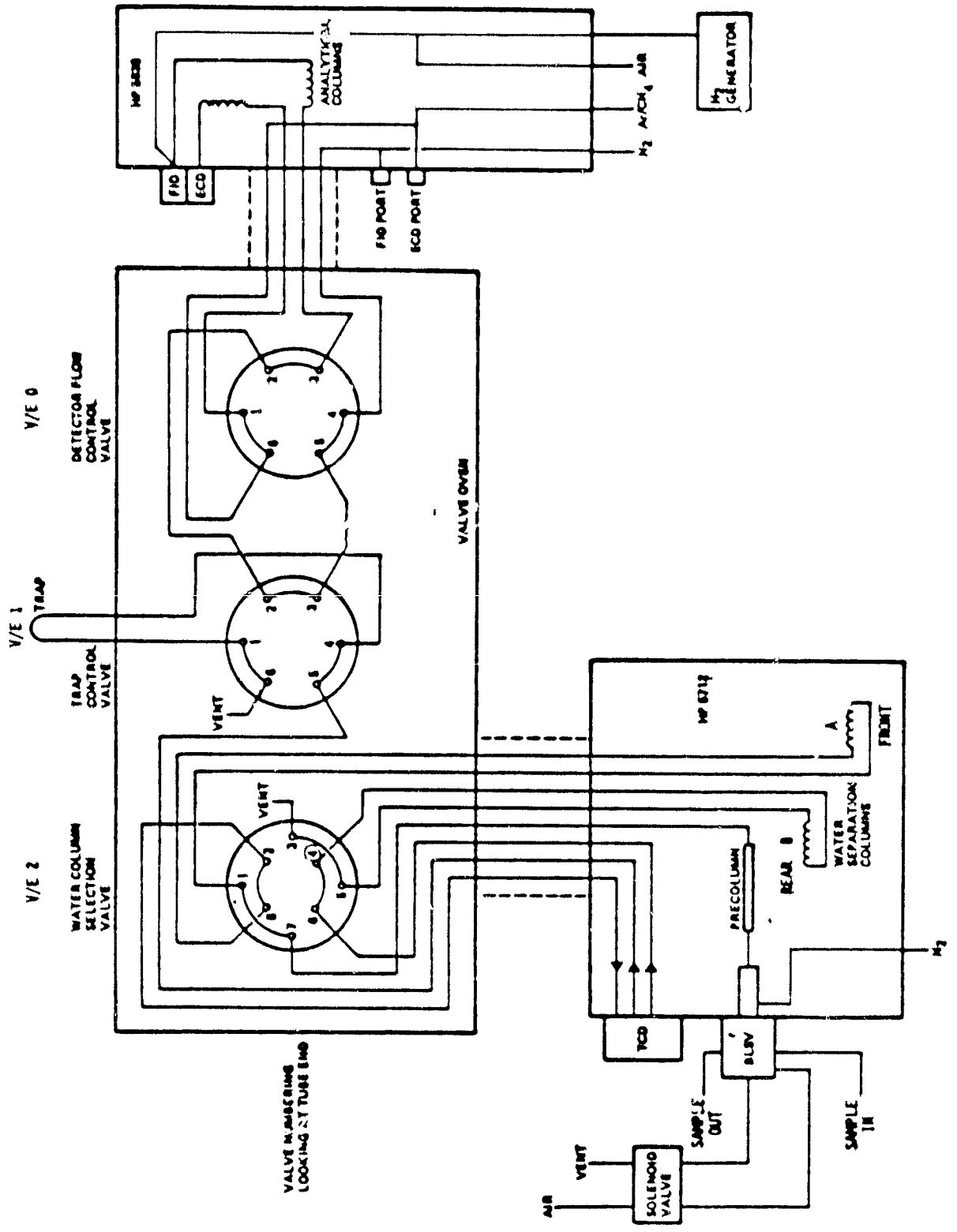

Figure 8 Automated Gas Chromatograph Water Analysis System Flow Schematic

Before a water sample is processed, the Tenax trap is heated for 1 minute and purged with nitrogen. The analytical column is heated to 200°C for 5 minutes to remove any residual volatile materials. Valve 2 is rotated before each analysis, thus alternating the two identical water separation columns. This allows one preparative column to be used while the other preparative column is being purged. When the trap is cooled to about 25°C and the analytical column cooled to 80°C, the water sample analysis can proceed.

Sample (120 l) is injected into the preparative column by six pneumatic actuations (20 l per injection) of the liquid sampling valve. The sample is immediately volatilized as it passes through the 175°C heated port. The sample then passes through valve 2 and into the water separation column. As the sample passes through this column, the organics separate from the water fraction and are eluted first onto the trap. By monitoring the column effluent with the thermal conductivity detector, the organics are collected on the trap until just prior to the emergence of the water fraction. At this point, valve 1 is actuated to vent the water vapor to the atmosphere and put the trap in line with the analytical column.

The concentrated organics are desorbed by heating the trap to 285°C for 15 seconds. The organics are then carried into the column in the analytical gas chromatograph by the argon/methane carrier gas. The output from the electron capture detector of this gas chromatograph is transmitted to the WMS computer system where concentrations are calculated and stored.

The entire volatile organic analysis is completed in 50 minutes. The first 10 minutes is used to heat and purge both the trap and analytical column of any residual organic compounds. The next 10 minutes is required for the separation and collection of the organic fraction of the water sample. The last 30 minutes is required for the analysis of the volatile organic compounds and transmission of the data to the computer. The entire procedure is repeated each hour, 24 hours a day.

Total and Fecal Coliform

The coliform sensor is designed to automatically analyze water samples daily for coliform concentrations. Coliform bacteria characteristically evolve hydrogen gas during the metabolism of the disaccharide lactose. In solution, molecular H_2 (hydrogen) and H+ (hydrogen ion) establish an equilibrium in the presence of noble metals such as platinum according to the following equation:

$$H_2 \overset{Pt}{\rightleftharpoons} 2H^+ + 2e^-$$

The potential of this reaction may be measured using a commerical combination electrode such as Calomel-Platinum. It had been observed that the time from inoculation to detection of hydrogen is inversely proportional to the initial inoculation cell count for coliform organisms. The coliform detector quantifies organisms of this group on the basis of the hydrogen produced. Figure 9 is a flow schematic of the coliform detector.

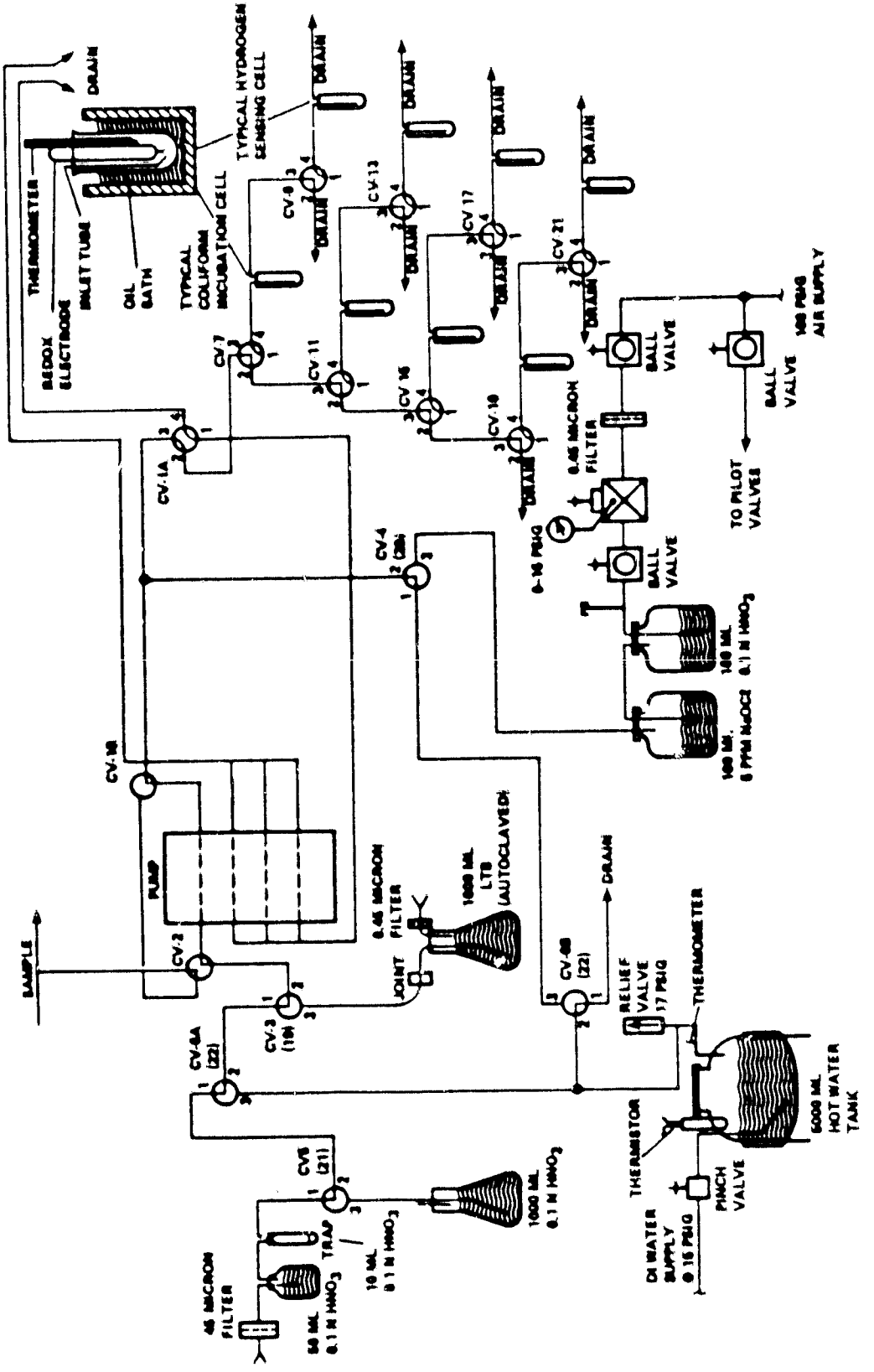

Figure 9 Coliform Sensor Flow Schematic

The coliform sensor is packaged in a standard 19-inch cabinet. The sensor includes four subsystems: Manual and automatic control switch panel, four incubator and four buffer cells, fluids storage and transfer equipment, and instrumentation. Manual and automatic control of the sensor is accomplished through a switch control panel. Automatic control of cleanup, buffer purging, nutrient fill, and inoculation procedures are provided by the computer. Manual control is available for performing maintenance procedures. The four incubator cells are serially connected by 1.6mm four-way Teflon valves to a common fluid fill-and-drain manifold. In addition, each nutrient cell is connected to a similar cell filled with 1.0% KH_2PO_4 buffer. The purpose of the buffer cells is the collection and measurement of hydrogen gas. The cells are 25mm by 15mm borosilicate glass tubes. The top of each cell is fitted with a silicone stopper molded for two 1.6mm fill-and-vent tubes, a 12mm combination electrode, and a mercury thermometer. Teflon is used wherever possible to enhance cleaning. Each of the cell tubes is immersed in a mineral oil bath which can be individually controlled at temperatures of 35°C (total coliform) or 44.5°C (fecal coliform) and a bacteriostat temperature of 85°C. The bath is heated with electrical resistance heaters, and temperatures are maintained with solid state proportional controllers. The buffer cells are operated at room temperature.

The fluids storage and handling section includes valves, peristaltic pump, reagent storage containers, regulated facility air, and hot demineralized water. Air supplies are filtered to 0.45 micron and washed in 0.1 N nitric acid. Water is heated to 100°C with 30 minutes retention time to effect sterilization. Organism growth is monitored with one combination electrode per cell. The electrode signal is conditioned with high impedance amplification and multiplexed to the computer for visual display and engineering unit printout. Temperatures may be monitored visually with a mercury thermometer.

The coliform sensors' cleanup and inoculation processes are controlled by a 57-step computer program. The cleanup and inoculation processes are shown in Table 3. The first 45 steps involve evacuating the previous sample, cleaning and sterilizing the reaction cells, purging the hydrogen gas from the buffer cells, and introducing fresh broth into the incubator cells. Step number 46 is a 48-hour holding step which was devised to allow the operator a variable waiting period between inoculations. The remaining steps inoculate the sample with the final step being a holding step during which hydrogen production by organism growth is monitored by the EVE minicomputer.

An extensive amount of work was done prior to the test period to develop a series of calibration curves. The information gathered was used to compare this sensor to another which used an impedance measuring technique, establish sensitivity and reproducibility limits, and to demonstrate the degree of agreement between the sensor values and the MPN values from the laboratory.

In order to calibrate the sensor, seeded samples were run and the reaction times were plotted against the lab MPN values obtained on the sample. The samples consisted of serial dilutions of unchlorinated secondary effluent using chlorinated secondary effluent (which had been dechlorinated) as diluent. The dechlorinated water was used as diluent in order to approximate the chemical composition of real-world samples. Figures 10 and 11 show the fecal and total

TABLE 3

COLIFORM SENSOR SCHEDULE

STEP	VALVE ENERGIZED TIME	CUMULATIVE TIME	ENERGIZED VALVES	2/28/81
1.	0: 0: 0	0: 0: 0	17,21,23,	DRAIN CELLS 17 = DRAIN 21 = HNO_3 FLOW 23-39 = INLET VALVES FOR CELLS 1,3,5,7
	0: 5: 0	0:13: 0	17,21,31,	
3.	0: 5: 0	0:18: 0	17,21,27,	
4.	0: 5: 0	0:23: 0	17,21,35,	
5.	0:15: 0	0:38: 0	21,23,	ADD HNO_3 TO CELLS 21 = HNO_3 23-39 = INLET VALVES FOR CELLS 1,3,5,7
6.	0:15: 0	0:53: 0	21,31,	
7.	0:15: 0	1: 8: 0	21,27,	
8.	0:15: 0	1:23: 0	21,35,	
9.	0: 4: 0	1:27: 0	20,	FLUSH MAIN LINE WITH AIR 20 = COMPRESSED FILTERED AIR
10.	0: 1: 0	1:28: 0	20,35,	FLOW COMPRESSED AIR THRU HNO_3 IN CELLS TO AGITATE 20 = COMPRESSED AIR 23-39 = INLET VALVES FOR CELLS
11.	0: 1: 0	1:25: 0	20,27,	
12.	0: 1: 0	1:30: 0	20,31,	
13.	0: 1: 0	1:31: 0	20,23,	
14.	0: 5: 0	1:36: 0	17,21,35,	DRAIN HNO_3 FROM CELLS AND BEGIN 95° HEAT SOAK 17 = DRAIN 21 = HNO_3 FLOW 23-39 = INLET VALVES 53-61 = 95° (INCUBATORS)
15.	0: 5: 0	1:41: 0	17,21,27,	
16.	0: 5: 0	1:46: 0	17,21,31,	
17.	0: 5: 0	1:51: 0	17,21,23,53,	
18.	0:15: 0	2: 6: 0	22,23,49,53,	FLUSH WITH HOT D.I. HOH AND A SOAK 22 = HOT D.I. HOH 39-23 = CELL VALVES 53-61 = 95° (INCUBATORS)
19.	0:15: 0	2:21: 0	22,31,45,49,53,	
20.	0:15: 0	2:36: 0	22,27,41,45,49,53,	
21.	0:15: 0	2:51: 0	22,35,41,45,49,53,	
22.	0: 8: 0	2:59: 0	17,21,23,41,45,	DRAIN HOH FROM CELLS START SECOND SOAK 17 = DRAIN 21 = HNO_3 FLOW 23-39 = INLET VALVES
23.	0: 8: 0	3: 7: 0	17,21,31,41,45,	
24.	0: 8: 0	3:15: 0	17,21,27,41,	
25.	0: 8: 0	3:23: 0	17,21,35,41,	
26.	0: 5: 0	3:28: 0	20,	CLEAR MAIN LINE WITH AIR 20 = AIR
27.	0: 5: 0	3:33: 0	20,23,25,	PURGE BUFFER CELLS WITH COMPRESSED AIR 20 = AIR 23-35 NUTRIENT CELL INLET 25-37 BUFFER CELL INLET
28.	0: 5: 0	3:38: 0	20,27,29,	
29.	0: 5: 0	3:43: 0	20,31,33,39,	
30.	0: 5: 0	3:48: 0	20,35,37,	
31.	0:10: 0	3:58: 0	19,41,45,49,53,	FLUSH MAIN LINE WITH NUTRIENT 19 = NUTRIENT FLOW
32.	0: 4: 0	4: 2: 0	19,23,41,45,49,53,	NUTRIENT FILL AND SOAK 19 = NUTRIENT 23-35 INLET VALVES 41-45 95° FOR 4 NUTRIENT CELLS
33.	0: 4: 0	4: 6: 0	19,31,41,45,49,53,	
34.	0: 4: 0	4:10: 0	19,27,41,45,49,53,	
35.	0: 4: 0	4:14: 0	19,35,41,45,49,53,	

TABLE 3

COLIFORM SENSOR SCHEDULE

(Continued)

STEP	VALVE ENERGIZED TIME	CUMULATIVE TIME	ENERGIZED VALVES	2/20/81
36.	0: 5: 0	4:19: 0	20,41,45,49,53,	FLUSH MAIN LINE WITH AIR 20 = COMPRESSED AIR
37.	0: 1: 0	4:20: 0	23,41,45,49,53,	OPEN NUTRIENT CELL INLET VALVES TO ALLOW PUMP TO DRAIN CELL LINES INTO CELL COMPLETE SOAK
38.	0: 1: 0	4:21: 0	31,41,45,49,53,	
39.	0: 1: 0	4:22: 0	27,41,45,49,53,	
40.	0: 1: 0	4:23: 0	35,41,45,49,53,	
41.	0:16: 0	4:39: 0	22,41,45,49,53,	FLUSH MAIN LINE WITH HOT DI H2O AND COMPLETE SOAK 22 = HOT DI H2O
42.	0: 8: 0	4:47: 0	21,41,45,49,53,	FILL MAIN LINE WITH HNO_3 21 = HNO_3
43.	0: 6: 0	4:53: 0	17,21,41,45,49,53,	FLUSH SAMPLE CUP LINE WITH HNO_3
44.	0: 8: 0	5: 1: 0	22,	FLUSH MAIN LINE WITH HOT DI
45.	0: 6: 0	5: 7: 0	17,22,	FLUSH SAMPLE CUP LINE WITH DI
46.	48: 0: 0	53: 7: 0	22,	HOLDING STEP FLUSH MAIN LINE WITH HOT D.I.
47.	0:10: 0	53:17: 0	18,	FLUSH MAIN LINE WITH SAMPLE 18 = SAMPLE VALVE
48.	0: 4: 0	53:21: 0	18,23,	FILL CELLS WITH (1 ml) OF SAMPLE 18 = SAMPLE VALVE 23-38 CELL VALVES
49.	0: 4: 0	53:25: 0	18,27,	
50.	0: 4: 0	53:29: 0	18,31,	
51.	0: 4: 0	53:33: 0	18,35,	
52.	0: 6: 0	53:39: 0	20,	CLEAR MAIN LINE WITH COMPRESSED AIR
53.	0: 1: 0	53:40: 0	23,	OPEN INLET VALVES TO ALLOW PUMP TO DRAIN CELL LINES INTO CELL COMPLETE SOAK
54.	0: 1: 0	53:41: 0	27,	
55.	0: 1: 0	53:42: 0	31,	
56.	0: 1: 0	53:43: 0	35,	
57.	0: 1: 0	53:44: 0	22,25,29,33,37,39,	FLUSH MAIN LINE WITH HOT D.I. OPEN BUFFER CELL INLET VALVES VALVES REMAIN ENERGIZED UNTIL NEXT CLEANUP 22 = D.I. 25-37 = INLET VALVES 39 = DUMMY VALVES

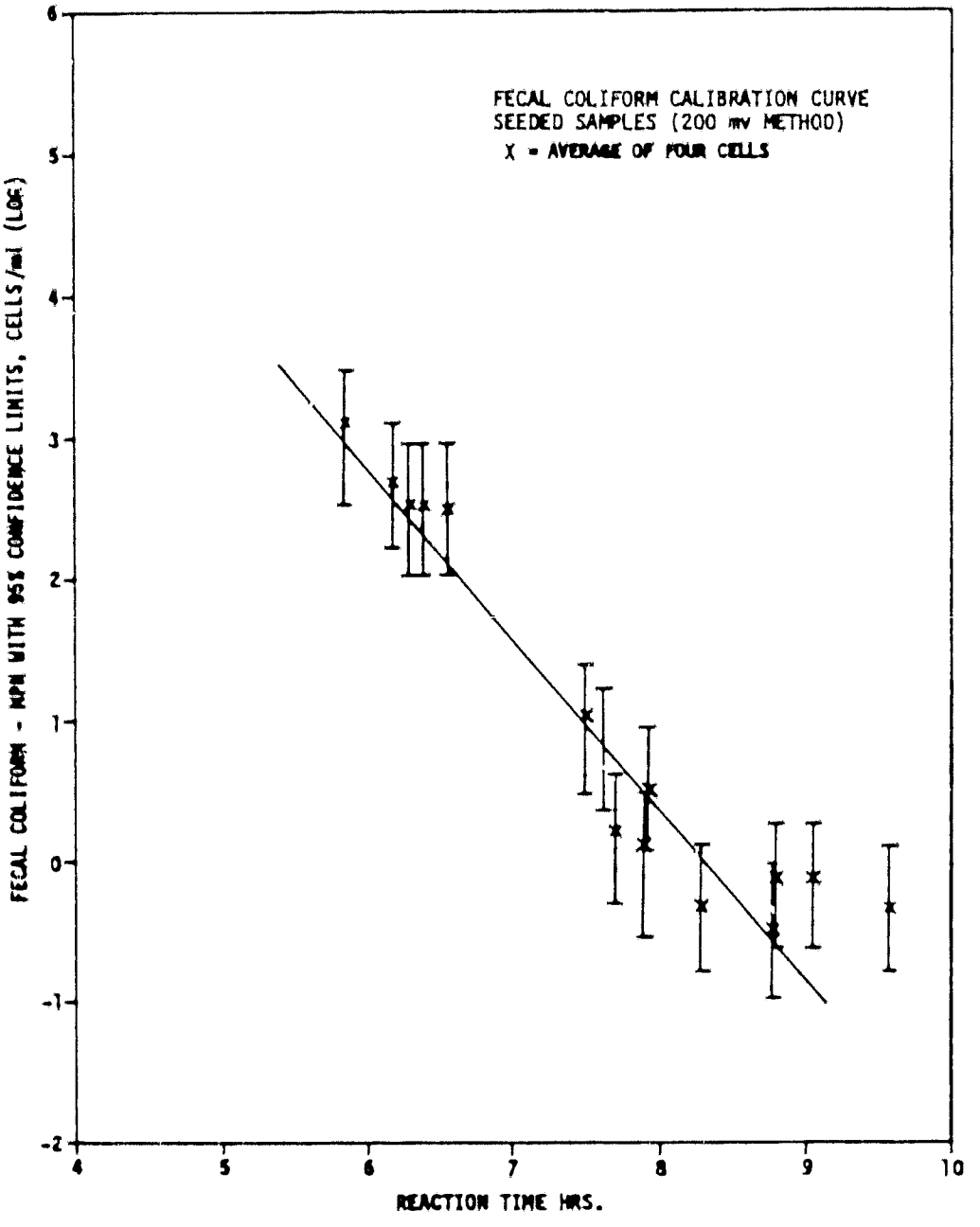

Figure 10 Coliform Sensor Calibration-Fecal Coliform

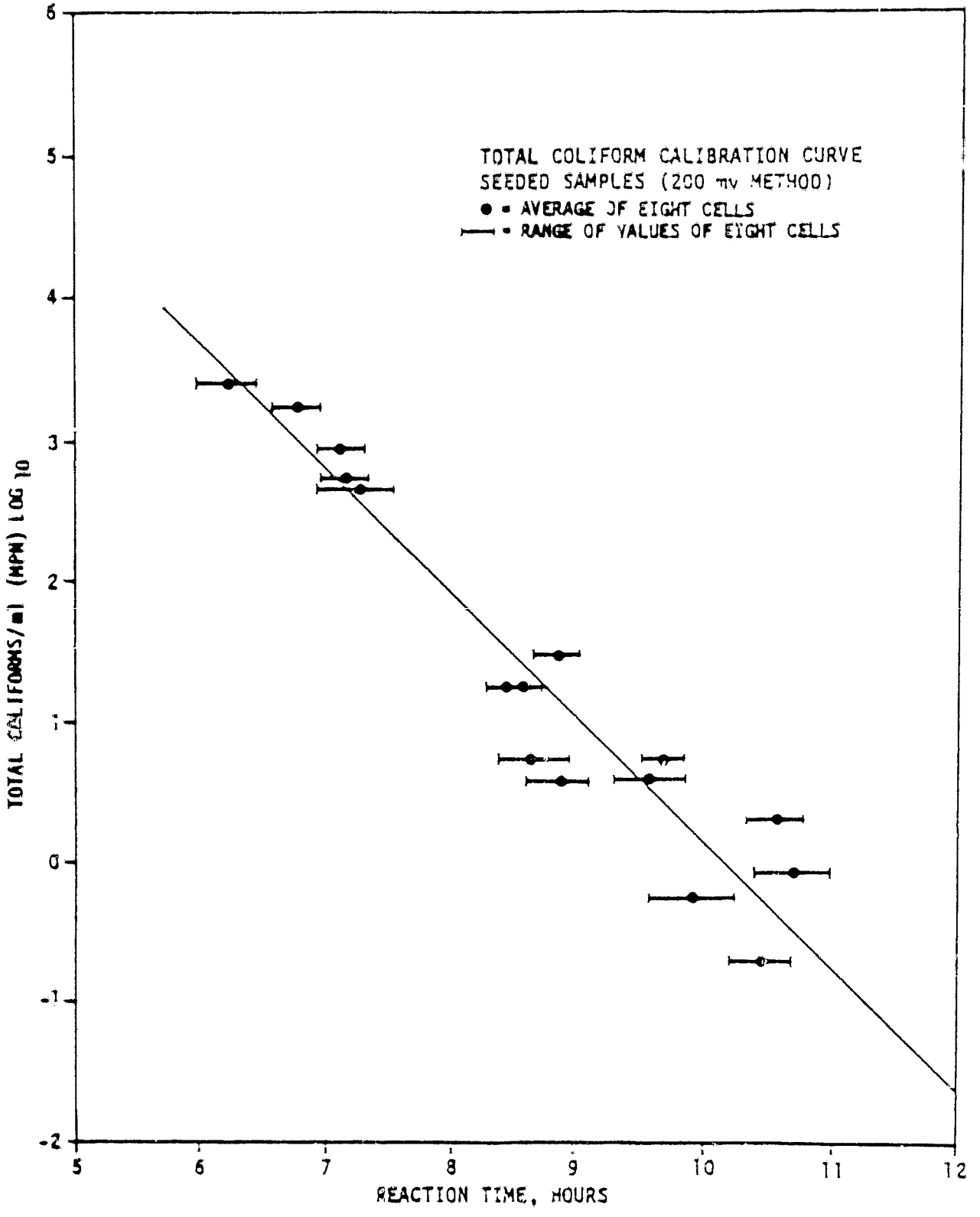

Figure 11 Coliform Sensor Calibration-Total Coliform

calibration curves which were obtained in the manner mentioned above. Linear regression analyses were run and gave the slope, y intercept, and r values for each calibration. For the fecal coliform calibration, the values were -1.26, 10.45 hrs., and 0.95, respectively. For the total coliform the calibration curve values were -0.9, 9.04 hrs., and 0.95, respectively. By using the equation $y = mx+b$, the unknown (the original number of coliform bacteria in the sample) may be calculated. Whereas y equals the original coliform concentration, m equals the slope, and b equals the y intercept. The reaction time is designated as the amount of time required to register a 200 mv drop from the electrode output.

In the course of operating the coliform sensor, several cultures of bacteria (coliform and noncoliform) were obtained. It was discovered that several strains of noncoliform bacteria mimicked the electrode response of coliform bacteria. This was a revelation in that previous experience had shown that noncoliform bacteria were incapable of driving the electrodes to the maximum negative point (-500 mv). These particular cultures, however, gave electrode responses equal to those of coliforms.

After it became apparent that the electrode response was influenced by end products of metabolism other than hydrogen, a new cell configuration was devised allowing four of the eight test cells to see only gases evolved in the four test cells containing broth. This provides four pairs of test cells with each pair consisting of a broth cell and a buffer cell. This is the configuration currently being used.

Data Acquisition and Report Generation System

The WMS was developed as a method for providing automatic operation and control of the instrumentation and sample collection system necessary to determine the physical/chemical and biological activity of water discharged from waste treatment facilities. Two computer systems, ADAM (Air Data Acquisition and Monitoring) and EVE (Environmental Verification and Evaluation), accomplish this objective by separate data acquisition and report generation tasks. ADAM is a commerical software package developed to control air quality monitoring stations which acquire and check data, perform engineering unit conversions and automatic instrumentation standardization and calibration, and data reporting. EVE is a companion program developed to reformat the ADAM data for retention and display, to operate and control biological sensors and a gas chromatograph, and to plot or analyze the results.

The separate computer systems for data acquisition and report generation were developed to utilize the proven data processing capabilities of the ADAM system and provide flexibility to generate various reports and allow future expansion. The proprietary aspects of the ADAM software do not allow program modifications to be made to the data acquisition system; therefore, any required changes are performed on the EVE report generation system which is coded in FORTRAN and resides on the disk system.

The combined system of computers provides a wide range of capabilities for immediate determination and evaluation of water quality. Instantaneous and historical reports are available for display on either a CRT for immediate review or a line printer for hard copies or plotted results. The ADAM system was purchased from Monitor Labs, Inc., San Diego, CA, and the EVE system was developed by Boeing Aerospace Company to provide additional reporting and control capability not available in ADAM. ADAM is a stand-alone operating system that functions independently from EVE and operates and controls the sample collection system and the commerical sensors that measure the physical and chemical activity of the water samples. EVE utilizes the Data General Corporation RDOS (Real-Time Disk Operating System) to acquire the ADAM data, process and control the biological sensors, acquire the gas chromatograph data, and store and report the results.

The commercial sensors are hardwired to the ADAM system. These include total organic carbon, turbidity, dissolved oxygen, pH, ammonia, nitrate/nitrite, conductivity, temperature, sodium, residual chlorine, hardness, sample pumping pressures and reclamation plant chemical clarification operational parameters (influent flow pH, recycle flow, waste flow and sludge density). There are 40 data channels available for continuous real-time monitoring.

The computer system is secured in three adjoining equipment racks as shown in Figure 12. The ADAM system is racked within the left equipment bay and the EVE system is racked within the center and right equipment bays. The ADAM computer system, Figure 13, consists of a Data General NOVA 1200 computer with 24K words of memory, a Monitor Labs Data Logger, Time-of-Year Clock, and a peripheral device control interface; a Remex paper tape reader/punch; and an NCR thermal printer and keyboard. The EVE system computer equipment, Figure 14, consists of a Data General NOVA 3D computer with 64K words of mapped memory, a disk system with one fixed and one removable cartridge with 10 megabytes storage capacity, a magnetic tape, and a communication chassis with a four-line asynchronous multiplexer; a Monitor Labs peripheral device control interface and an A/D converter; two TEC CRT data screens and keyboards; and a Versatec matrix printer/plotter. Separate cables are provided for the Remex paper tape reader/punch and Data General magnetic tape to allow access by either computer system. Except for the magnetic tape and the communication chassis on the EVE system, all peripheral communication is accomplished through each Monitor Labs device control interface. The Data General communication chassis is used on the EVE system to receive the ADAM commercial sensor data and the gas chromatograph data via two EIA RS232C data lines that are multiplexed for access by the operating system. A second CRT is used on the EVE system for background communication with the operating system.

The Digital Clock provides the main system time base to sample the digital data from the Data Logger. A selectable time pulse is transmitted through the Interface to the NOVA 1200 cpu. The NOVA 1200 cpu responds by calling the remote station via a Serial Input/Output device in the interface unit. The remote station then reads the analog input signals and proceeds to transmit the digital data. The NOVA 1200 cpu checks the incoming data for errors, stores the information, and performs calculations for transmission to the communication chassis.

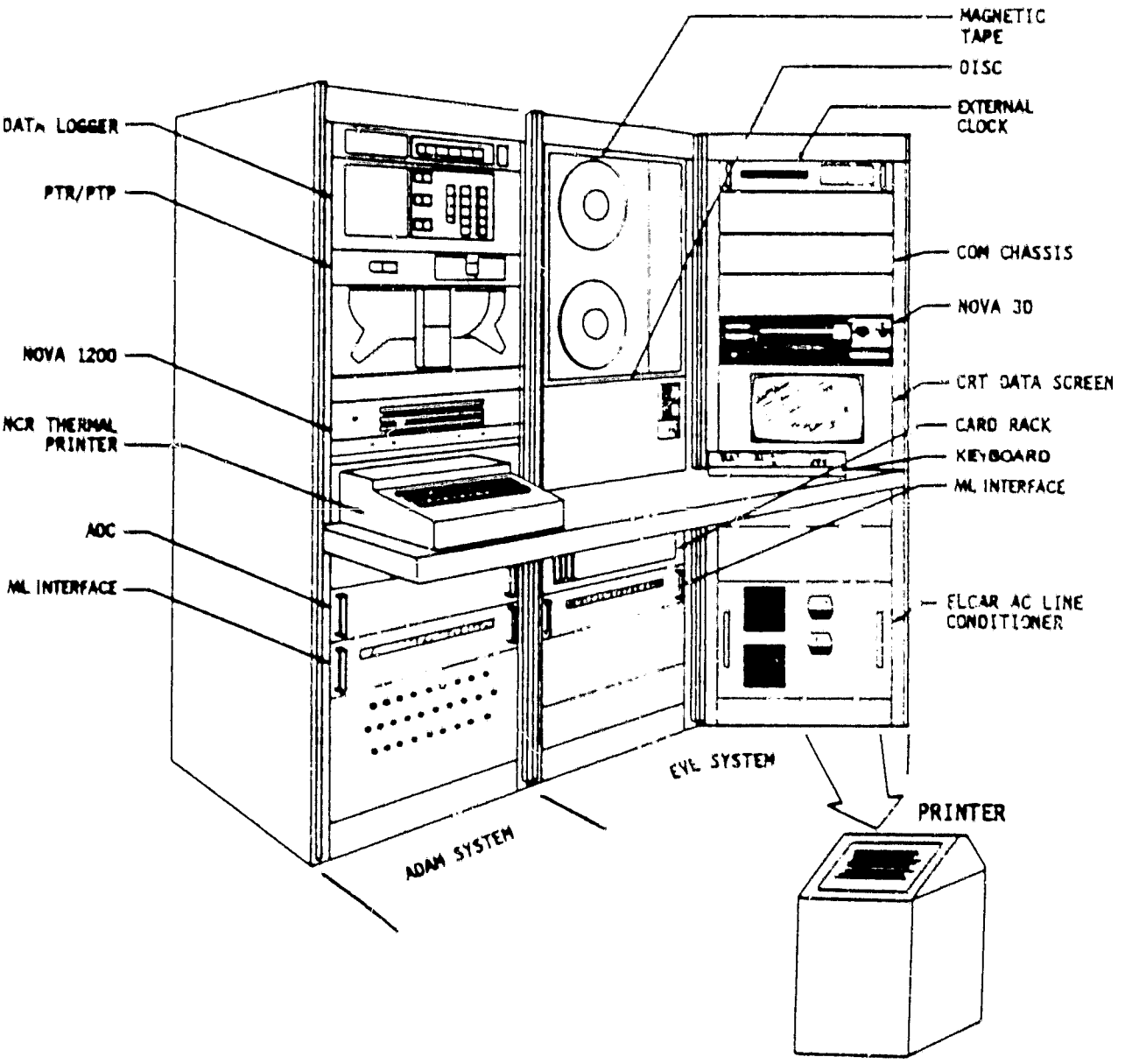

Figure 12 WMS Computer System

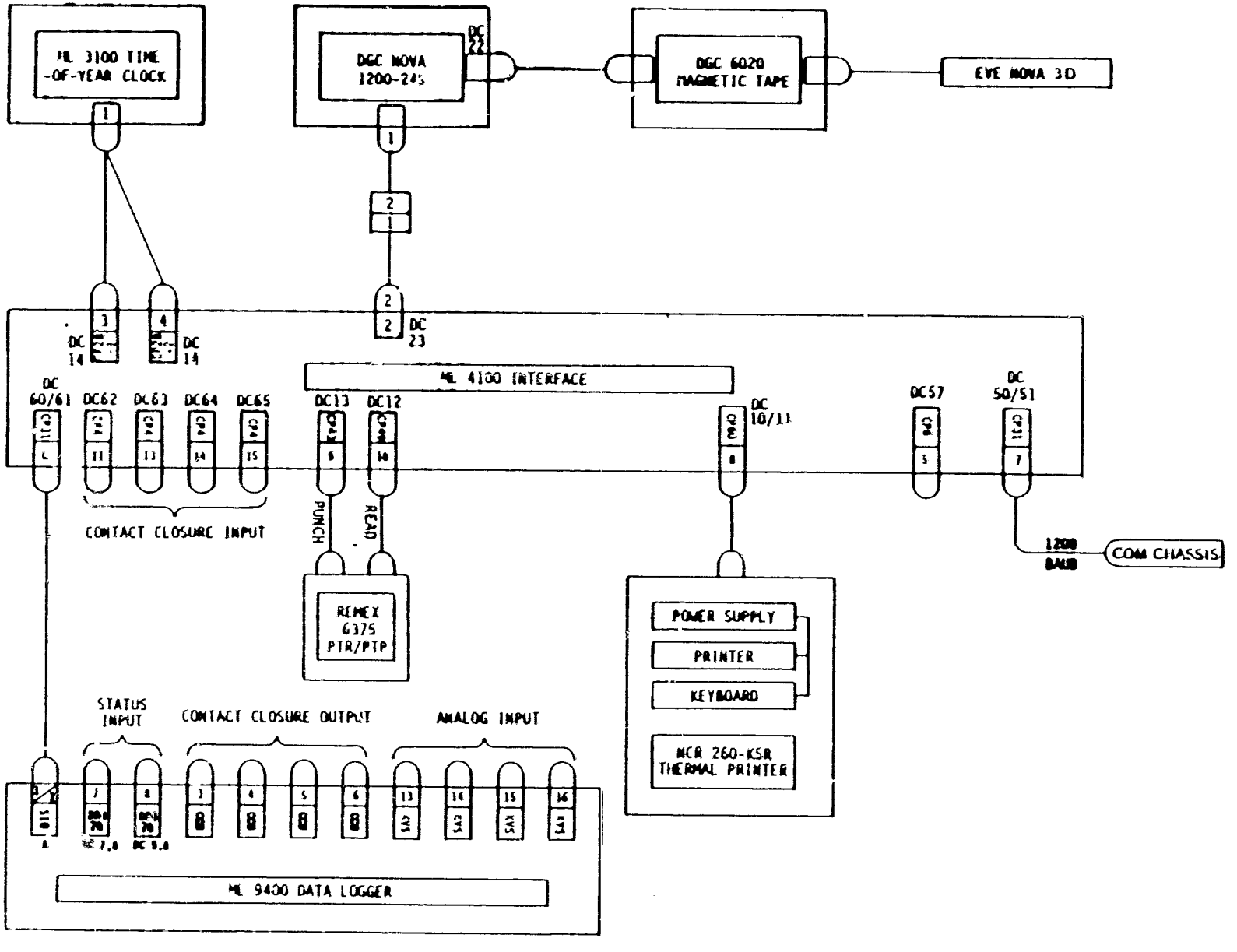

Figure 13 ADAM System Configuration

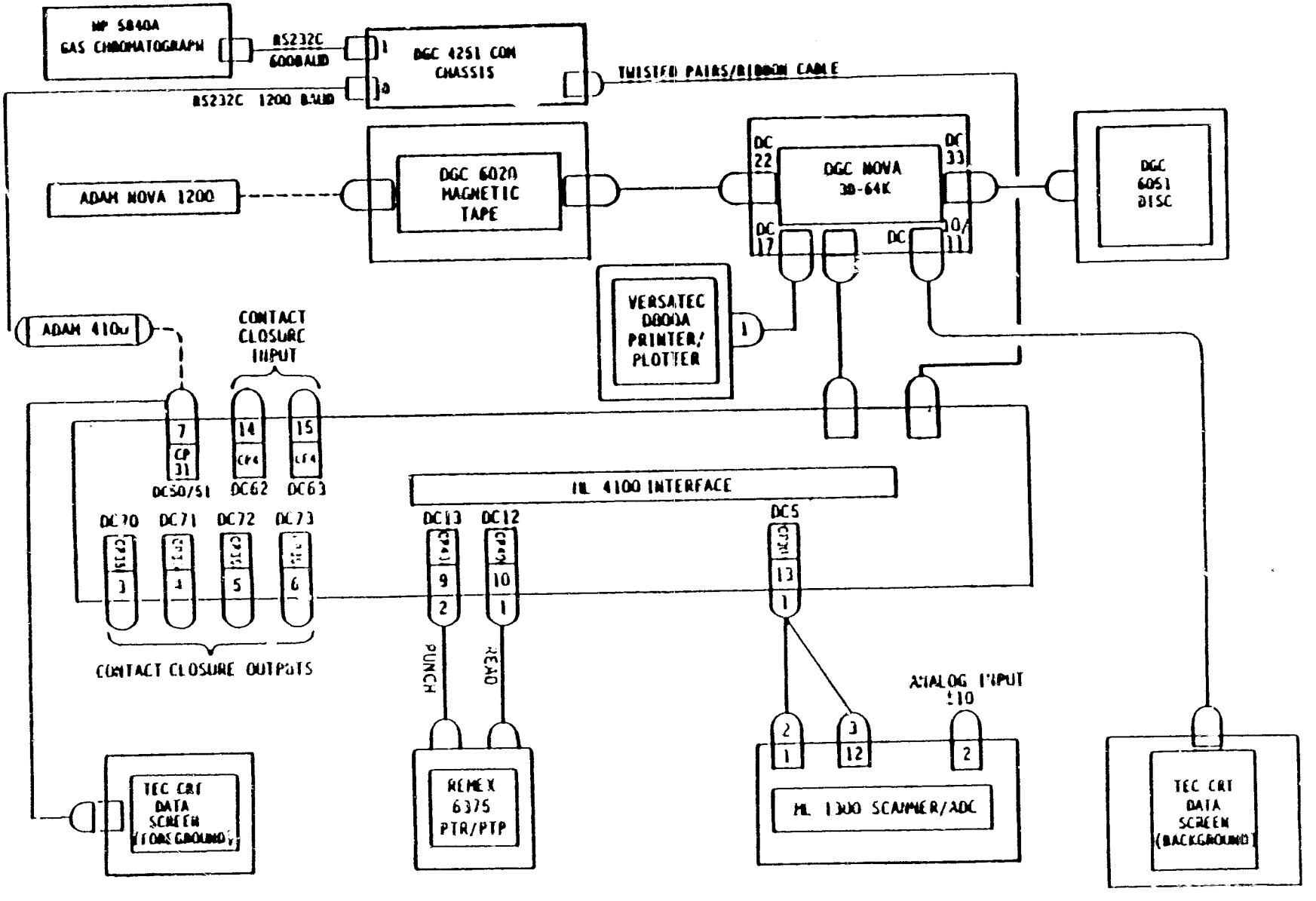

Figure 14 EVE System Configuration

Operator control of the WMS is provided by a separate communication device for each computer system. The ADAM system communication is provided by a thermal printer and keyboard. The EVE system communication is provided by two CRT data screens and keyboards. Hard copies of the EVE reports and plotted results are printed on a line printer. A data scan is performed each minute by the ADAM system, the data are transmitted to the EVE system, and the results are displayed on one of the CRT data screens. Instrument status, current or instantaneous data, and previous or historical data from EVE are monitored. Required channel calibration data and standardization valve actuation data for ADAM are entered on the keyboard.

The WMS provides the capability to automatically monitor 40 parameters each minute and generates reports for instantaneous data or for historical data of the current day or any previous day within a 3-month period. Instantaneous data reports provide the previous 1-minute value, and the previous 15-minute, 30-minute, and hourly averages as well as the running average for each of the 40 available channels. Historical data reports provide daily averages, instantaneous and hourly peak values, and the time of day each occurred. Both hourly averages and daily averages may be plotted simultaneously with data processing and display.

The computer operating manual with a detailed software description is contained in Reference 9.

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